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Meeting Report: Long term monitoring of global vegetation using moderate resolution satellites

The international community has long recognized the need to coordinate observations of Earth from space. In 1984, this situation provided the impetus for creating the Committee on Earth Observation Satellites (CEOS), an international coordinating mechanism charged with coordinating international civil spaceborne missions designed to observe and study planet Earth. Within CEOS, its Working Group on Calibration and Validation (WGCV) is tasked with coordinating satellite-based global observations of vegetation. Currently, several international organizations are focusing on the requirements for Earth observation from space to address key science questions and societal benefits related to our terrestrial environment. The **Global Vegetation Workshop**, sponsored by the WGCV and held in Missoula, Montana, 7-10 August, 2006, was organized to establish a framework to understand the inter-relationships among multiple, global vegetation products and identify opportunities for:

- Increasing knowledge through combined products,
- Realizing efficiency by avoiding redundancy, and
- Developing near- and long-term plans to avoid gaps in our understanding of critical global vegetation information.

The Global Vegetation Workshop brought together 135 researchers from 25 states and 14 countries to advance these themes and formulate recommendations for CEOS members and the Global Earth Observation System of Systems (GEOSS). The eighteen oral presentations and most of the 74 posters presented at the meeting can be downloaded from the meeting website (www.ntsg.umt.edu/VEGMTG/). Meeting attendees were given a copy of the July 2006 *IEEE Transactions on Geoscience and Remote Sensing* Special Issue on Global Land Product Validation, coordinated by the CEOS Working Group on Calibration and Validation (WGCV). This issue contains 29 articles focusing on validation products from several of the sensors discussed during the workshop.

A framework for long-term global vegetation monitoring

Perhaps the most remarkable component of the workshop was the number of global vegetation monitoring products available from the current suite of seven moderate resolution sensors (0.5 – 1.0-km; ATSR, AVHRR, MODIS, SPOT-VEGETATION, MERIS, MISR, and POLDER), with at least two replacement sensors (GMES Sentinel-3 and VIIRS) planned for the next several years. These sensors accurately quantify land cover type and detect the changes in land cover fundamental to assessing global change of the biosphere. In addition to land cover, consistent spatial and temporal information on vegetation health and productivity, such as albedo, vegetation indices (VI), leaf area index (LAI), the fraction of absorbed photosynthetically active radiation (FPAR), and gross (GPP) and net (NPP) primary production at an 8-16 day intervals, are available from a number of satellites,. Data regarding fire location, intensity, and effects are becoming increasingly important, and satellites provide the only global real-time tracking of fire-related biospheric changes.

With the growing number of products there remain challenges to data access and uniformity as well as developing an understanding of the relationship between the multiple products. Workshop attendees agreed that the commercialization of, or increasing user costs associated with, global vegetation data will greatly reduce its use. Furthermore, accessibility varies by satellite. For example, MODIS near real-time data are freely available after processing, normally 8-16 days after retrieval, and several fire products are sent to direct

broadcast stations from the satellite daily. SPOT-VEGETATION products are available in near real-time to commercial users and freely accessible to the larger scientific community after 3 months. An assessment of the current system should involve **both** the agencies responsible for the sensors (e.g., NASA, ESA) and resulting data **and** the international programs (e.g., CEOS, Global Climate Observing System [GCOS]) responsible for developing strategic plans for the use of those data. CEOS is playing a role in data format, access, and distribution issues through it Working Group on Information Systems and Services (WGISS).

Calibration and validation issues are more significant when using data from multiple sensors or products. At the meeting, at least five different global VI products and six different LAI products were demonstrated. These datasets differ in original source sensor, spatial and/or temporal resolution, atmospheric correction methodology, and other processing details. Such differences lead to confusion among users as to the "best" product for their particular research needs. Reducing such confusion requires a methodical, quantitative intercomparison of similar products, such as the groundbreaking work on the intercomparison of global LAI products presented at the workshop. These efforts improve understanding of the various products, enabling users to employ these products with confidence and better develop strategies for combining products.

Long-term data continuity necessitates deriving products from multiple satellites. International coordination initiatives are necessary for developing science quality long-term data records from existing and planned international assets. To ensure a consistent record, products must be validated against independent data of known accuracy. Ground-based measurements from both the Aerosol Robotic Network (AERONET) and FLUXNET network of flux towers have been vital to on-going validation studies. The AERONET (aeronet.gsfc.nasa.gov/) program is a federation of 371 ground-based remote sensing sites providing long-term measurements of aerosol properties used by the remote sensing community for validation of satellite estimates of albedo and the Bidirectional Reflectance Distribution Function (BRDF). FLUXNET (www-eosdis.ornl.gov/FLUXNET/) is an international network of more than 200 eddy covariance flux tower sites that measure CO_2, water vapor and energy exchange between terrestrial ecosystems and the atmosphere. Measurements from this network have been used to validate a number of satellite products such as LAI, GPP and, most recently, VI. Given the importance of these networks to sensor validation, meeting participants agreed that a plan be put into action at the national and international level to *maintain*, *enhance*, and *expand* these networks for improved validation in the future. Additionally, communication between ground-based measurement teams and satellite product validation teams must continue and improve, ensuring that the needs of both groups are met.

The majority of the global vegetation products discussed at the meeting derive from passive sensors operating predominantly in the visible and near infrared wavelengths. However, meeting attendees also discussed the untapped potential of global radar and microwave sensors, possibly combining them with optical instruments to improve upon existing products. Optical, radar, and microwave sensors and their products are now at a level of maturity to warrant consideration of global hybrid products. Furthermore, as satellite products mature, mechanisms must be put into place to transition proven research observations from global systems to the operational domain, such as the US National Oceanic and Atmospheric Administration (NOAA) has done with the Advanced Very High Resolution Radiometer (AVHRR) satellite series.

The Future of Biospheric Monitoring via Satellite

Many of the satellites currently in operation are nearing the end of their life spans and will cease operations by 2012. We need to coordinate future planned moderate resolution missions, potentially a cost-saving measure for all involved. For example, the satellites carrying the MODIS sensors could potentially retire in 2008 (Terra) and 2010 (Aqua). Ongoing delays to the launch of the U.S. National Polar-Orbiting Operational Environmental Satellite System (NPOESS) could leave NASA and US terrestrial remote sensing scientists with an irreplaceable data gap. It is imperative that the international community (through CEOS) work together to resolve issues involved with any potential data gaps, while concurrently resolving differences among satellite products. Discussions a the meeting suggested that CEOS initiate a pilot working group to study the efficacy of sensor constellations that would easily meet the spatial (<1 km) and temporal (1-3 day) needs of the vegetation remote sensing community. This working group would then suggest methods for producing combined products and international mission planning to reduce associated costs for each cooperating country. Current sensors should be considered as a test bed for future sensors as any degradation in current capability would represent a loss to the community.

Meeting attendees were inspired by the current state of remote sensing science, including the challenges and opportunities that it presents. As a result of this meeting, representatives will be working within the international framework to continue developing validation and intercomparison protocols and bring the needs of the moderate resolution remote sensing community to the appropriate international agencies such as CEOS, GCOS and GEOSS. Participants are planning to strengthen the lines of communication between this community and GEOSS, and simultaneously seek to reactivate the Global Terrestrial Observing System (GTOS) Net Primary Productivity demonstration product, perhaps combining it with related activities to better support vegetation remote sensing activities.

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